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Appendix N N92-10053

P-19

MPD Thruster Technology Workshop

NASA H.Q., Washington D.C.

16 May 1991

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IRS Presentation

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IRS

IRS Organigram

Institute for Space Systems
Messerschmid

Laboratory
Kurtz

Mission and System Analysis
Schöttle

- Development of numerical simulation and design tools
- Mission and system optimization of future space transportation syst.
- Performance assessment of airbreathing launch vehicles
- Altitude and orbit control

Electric Propulsion and Plasma Technics
Schrade
Auweter-Kurtz

- Development of MPD and thermal arcjets
- Simulation codes for MPD and thermal arcjet flows
- Cathode erosion
- Arc instabilities
- Development of arc-heaters
- High enthalpy wind tunnels
- Erosion and ablation of thermal protection materials

Space Technology and Utilisation
Messerschmid

- Space station design
- Microgravity research
- Numerical flow field and simulation methods
- Systems safety

Electric Propulsion and Plasma Wind Tunnel

Activities at the IRS

May 1991

Activity / Thruster	MPD (Selffield)	Arcjet			Reentry (Material-Tests)		Missions, Trajectories
Power Level	100 kW-1 MW	1 kW	< 20 kW	< 100 kW	$h_0 < 10^8$ J/kg		
Isp [km/s]	10 - 20	5 - 6	< 10	10 - 15			
Thrust [N]	5 - 20	0.1	> 1	> 10			
Propellant	Ar, N_2, H_2, NH_3	NH_3, H_2, N_2-H_2	N_2-H_2, H_2	NH_3, H_2			
Theories	Flowfield Stability Arc-Attachment Erosion	Constrictor Flow Heat Transport					Traject. - Optimizat.
Diagnostics	Emission Spectroscopy, el. Probes, Fabry-Perot Interferometry, Mechan. Probes, Mass Spectroscopy, Optical Temparature Measurement						
Status	Water Cooled Laboratory Devices	Radiation Cooled Lab. Model	Water Cooled Devices	Water Cooled Devices	PWK1 - IRS Operat. since 1987	PWK2 - IRS Operative	in Work
Contractors	USAF DFG BMFT	DARA		NASA (IST)	ESA / CNES, AMD-BA, AS, SEP, DO, MBB, MAN, DLR	DARA SFB ESA, FGE	

IRS Facilities

High DC Power Supply:

Power: $\leq$ 6 MW
Current: $\leq$ 48 kA
Ripple: $\leq$ 1 %

Vacuum System:

Four Stage Pump System:

1) 3 MTP 50.000 m^3/h roots pumps
   1 Alcatel 120.000 m^3/h roots pump

2) 1 MTP 50.000 m^3/h roots pump

3) 1 multiple slide valve type pump RV 500

4) Rotary vane pump BA 600

Total suction power: >200.000 m^3/h at 10 Pa
Tank pressure can be set

Vacuum tanks:

8 tanks connected to vacuum system

6 for plasma accelerator development
2 plasma wind tunnels

2 independent test stands for smaller thrusters or basic experiments

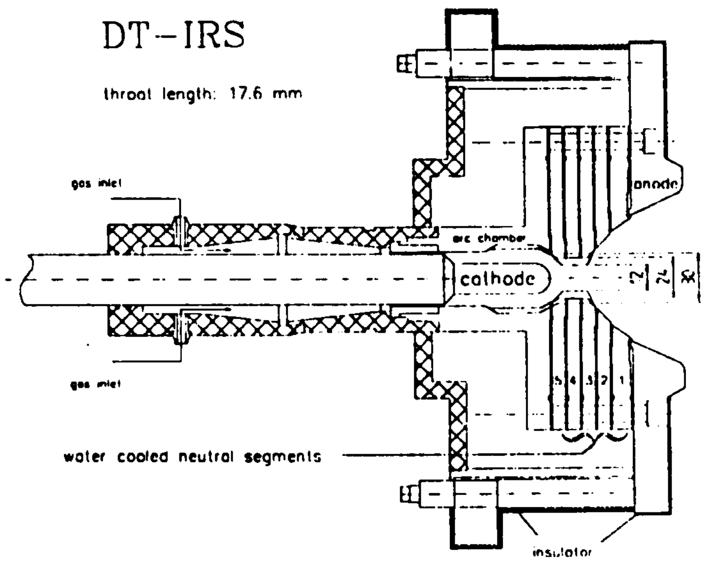
History of MPD Activities at IRS

1976	Begin of Building-Up of IRS Propulsion Laboratory
1982-1991	Cooperation Grants "Basic Processes of Plasma Propulsion" from AFOSR (analytical and numerical).
1982-1991	Cooperation Grants with interruptions "MPD Thruster Development" from AFRPL, AFOSR. 1987-1988 financed by the SDIO over ONR (experimental and numerical).
1989-1991	"MPD Thruster Instabilities", contract by the German Research Organisation DFG (theoretical studies).
1990-1993	"Plasma Instabilities in MPD Thrusters", contract by the German Ministry of Research BMFT (numerical and experimental; together with MAN).

IRS **History of Thermal Arcjet Activities at IRS**

1986-1990	"Arcjet Flow Analysis", contract by ESA/ESTEC (analytical and numerical).
1987-1990	"1 N Arcjet", sub-contract by ESA/ESTEC (experimental), main-contractor BPD, Italy.
1989-1991	"High Power Arcjet", Cooperation Grant by NASA (IST) (experimental and numerical studies).
1990-1993	"A 1 kW Hydrazine Arcjet", contract by the German Aerospace Agency DARA (together with MBB).

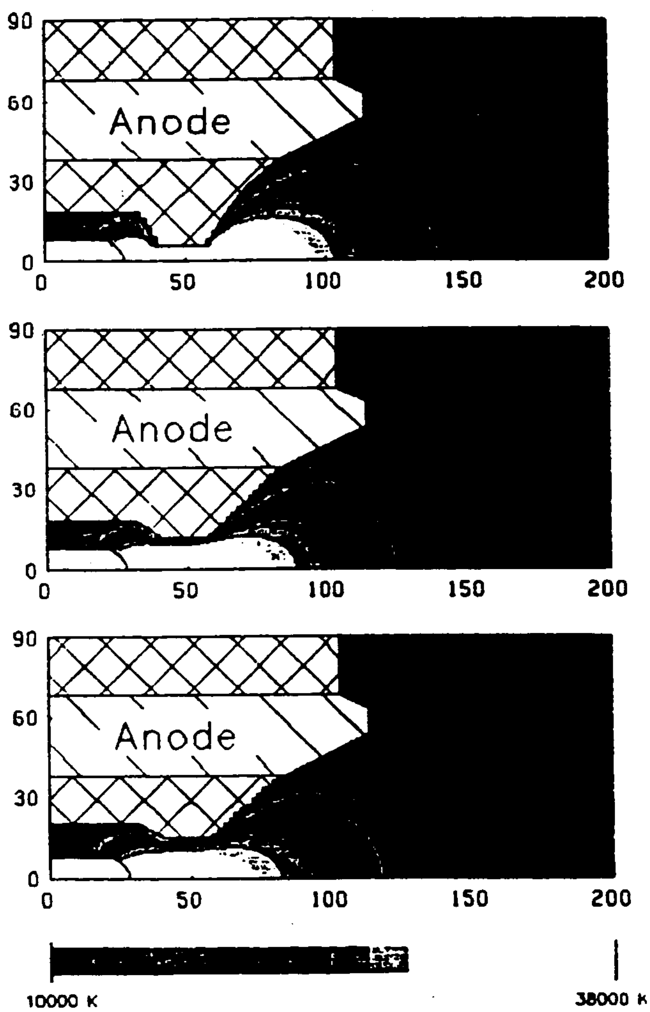
Nozzle Type Thruster DT-IRS



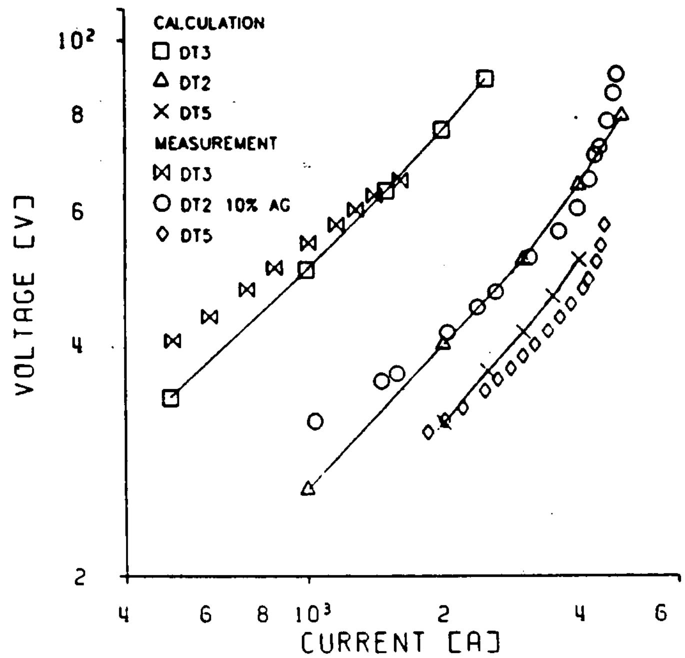
Configuration of the DT-Thrusters with different throat diameters

Maximum values reached with the DT2-Thruster with argon as propellant:

electrical power:	$P_{el} \leq$ **800 kW**
specific impulse:	$I_{sp} \leq$ **1500 s**
thrust efficiency:	$\eta_t \leq$ **25%**



Electron temperature distribution for three different throat geometries at 2 kA currant and a mass flow of 0.8 g/s.



Calculated and measured discharge voltage.

INSTITUT FÜR RAUMFAHRTSYSTEME UNIVERSITÄT STUTTGART

Nozzle Type MPD Thrusters

1.) Specific impulse limited to 1500 s because of low $\frac{I^2}{\dot{m}}$ - values.
(Onset - Phenomenon)

2.) Efficiency : not more than 30% achieved with experiments.
Expectation with higher massflow rates and higher power:
above 30% .

3.) High power limitations: Heat load of nozzle throat.

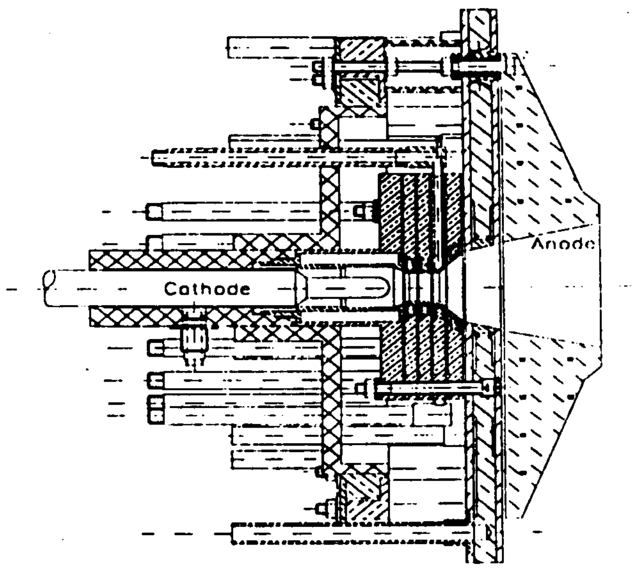
4.) Propellant: no significant difference in η and c_e with Ar, N_2, H_2,
lower $\frac{I^2}{\dot{m}}$ with H_2 and N_2.

5.) High power limits:
vacuum system (high power $\Rightarrow$ high mass flow rates)
(Influence of ambient pressure not so important with
selffield MPD's)

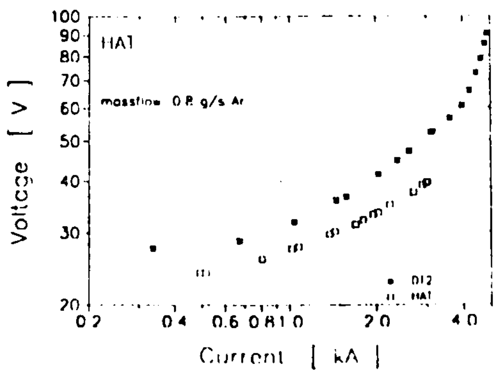
Research plans: Geometry optimization:

- Transition from nozzle to conical (flared) configurations.
- Radiation cooled anode.

IRS Hot Anode Thruster (HAT)



Configuration of the HAT-Thruster with radiation cooled anode



Voltage vs. current dependence for the HAT
in comparison with the DT2-Thruster

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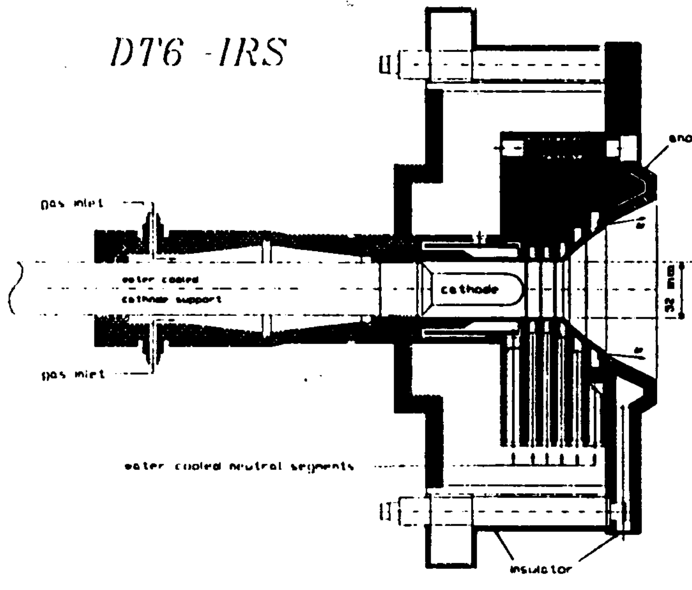
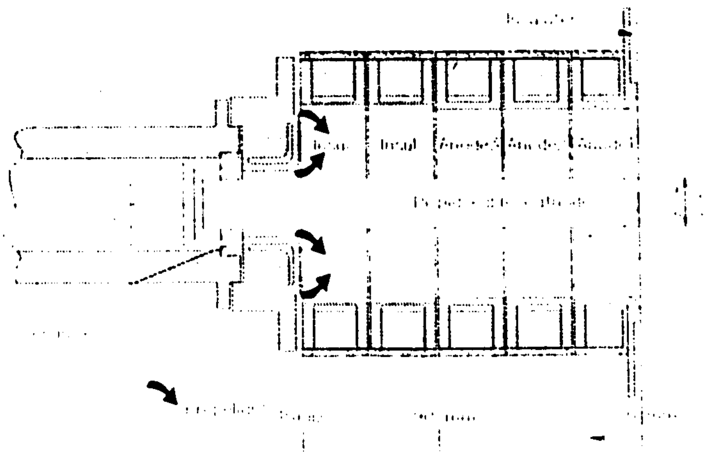
DT6-Thruster



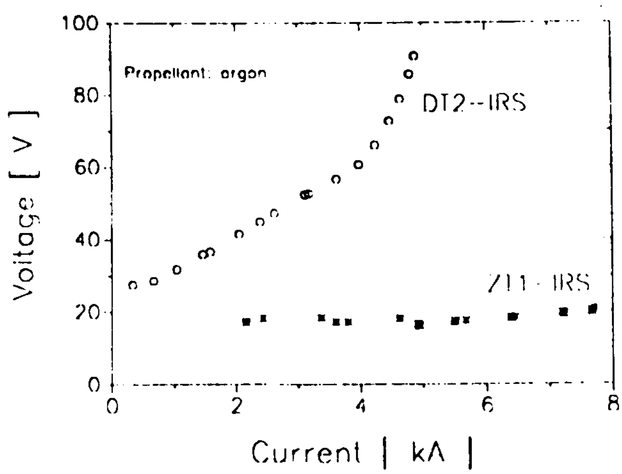
Configuration of the DT6-Thruster without throat constriction (in construction)

IRS

ZT1-Thruster



Configuration of the cylindical ZT1-Thruster



Voltage vs. current dependence for the ZT1- respectively DT2-Thruster with argon as propellant

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IRS

Cylindrical MPD thruster

1.) Higher onset ($\frac{I^2}{\dot{m}}$) than with nozzle type thrusters .

⇒ higher specific impulse possible.

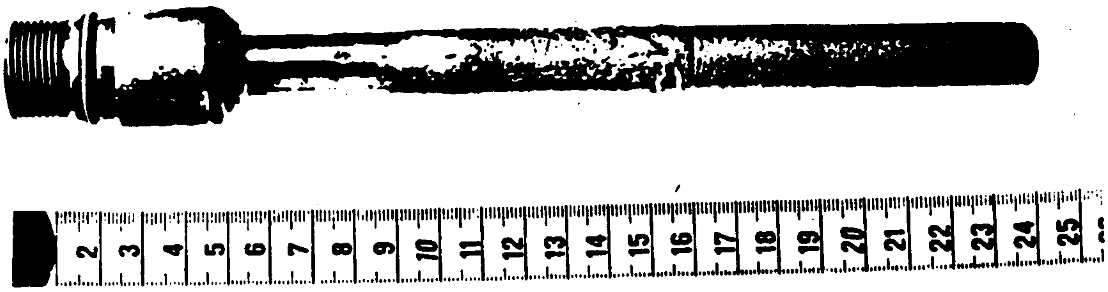
2.) Efficiency with continuous thruster not yet measured.
(Thrust balance in construction.)

3.) Lower voltage levels than with nozzle type thrusters.

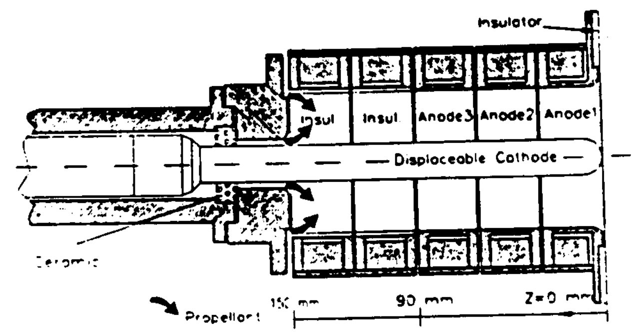
4.) High current issues:

- a) heat loads to anode (~ I)
- b) heat loads to cathode: can be solved by cathode geometrical configuration.

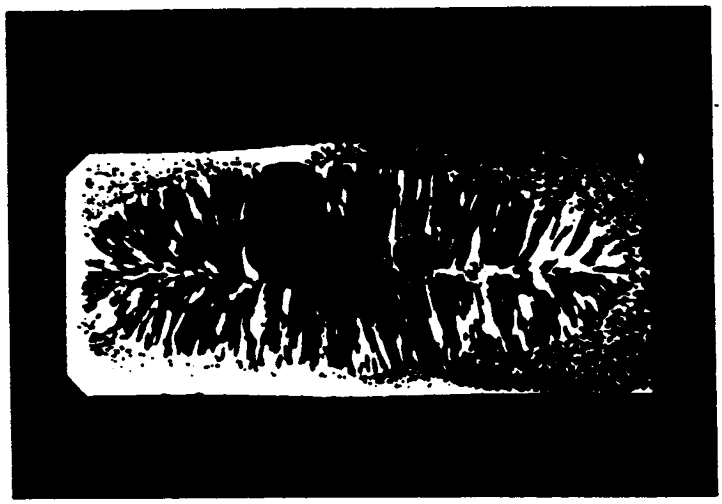
5.) High power limits:
vacuum system (high power ⇒ high massflow rates)
(Not so important with selffield MPD)



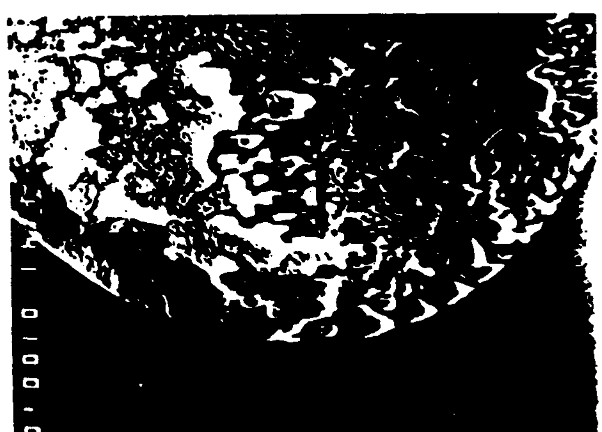
DAMAGED CATHODE OF THRUSTER ZT1



SCHEME OF THRUSTER ZT1



TYPICAL STRUCTURE OF AREA I (MELTED ZONE)



DETAIL OF THE VOID

Comparison

IRS

continuous MPD ⇔ quasi-steady MPD

Biggest problem: different cathode modes:

thermionic ⇔ cold

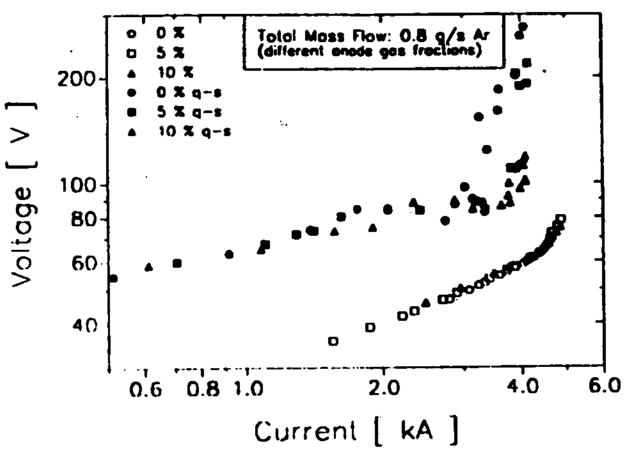
⇒ different arc attachments

⇒ different voltages

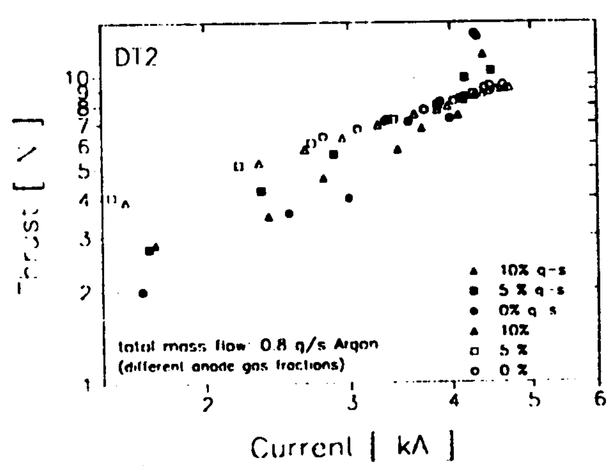
⇒ different current distributions

Comparison

continuous MPD ↔ quasi-steady MPD



Comparison of the voltage vs. current dependence for the continuous DT2-Thruster (open signs) and the quasi-steady MPD-Thruster (Closed signs)



Thrust vs. current curves for both thrusters

MPD-Thrusters

1.) Nozzle Type MPD-Thrusters (DT-IRS serie)

- Geometrical optimisation of the nozzle
  (experimental and numerical)

- Investigation of the plasma instabilities
  (experimental and numerical)

2.) Hot Anode Thruster (HAT)

- Reduction of the anode losses

3.) Cylindrical Thruster (ZT-IRS)

- Thrust measurments will hopefully resulting in

higher c_e !

IRS MMW-Thrusters

MMW thruster have to be cooled actively (at least partly).

Cathode heat loads could be solved by geometrical configuration.

How to address these issues:

1.) Measure heat loads in cooled devices and surface temperatures.

2.) Establish thermal models (numerical).

3.) Numerical variation of geometries and configurations.

4.) Validate with new device.

IRS Facility requirements

1.) Vacuum:

- for selffield MPD better 1 mbar
- for applied field MPD better 10^{-3} mbar

2.) Thrust balances for MMW-Thrusters are difficult to realize.